Space Qualification of GaN HEMTs - Guidance Document Announcement

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Background

History of some recent activities

- GaN HEMTs / MMICs have not yet been “officially” space qualified
  - *A number of Class A & B missions have targeted GaN power HEMT technology for usage in the next few years*
  - *Exciting opportunities for applications such as SSPAs, High Intercept LNAs*
- Existing techniques for accelerated testing and qual (as for GaAs) are inadequate:
  - *GaN may not have a single dominant failure mode*
  - *Temperatures/voltages/power densities are generally much higher*
  - *DC stressing alone may not be sufficient*
- In early 2017 an Aerospace draft document was written
  - *ATR-2017-01782 “DRAFT – Guidelines for Space Qualification of GaN HEMT Technology” J. Scarpulla & C. Gee, May 23, 2017*
- A working group was established to mature this document
  - *7 months of weekly meetings*
  - *Approx. 85 members / interested parties*
  - *Extensive edits and revisions were made based on many inputs*

Document is now in release cycle: TOR-2018-00691 “Guidelines for Space Qualification of GaN HEMT Technologies” J. Scarpulla, C. Gee

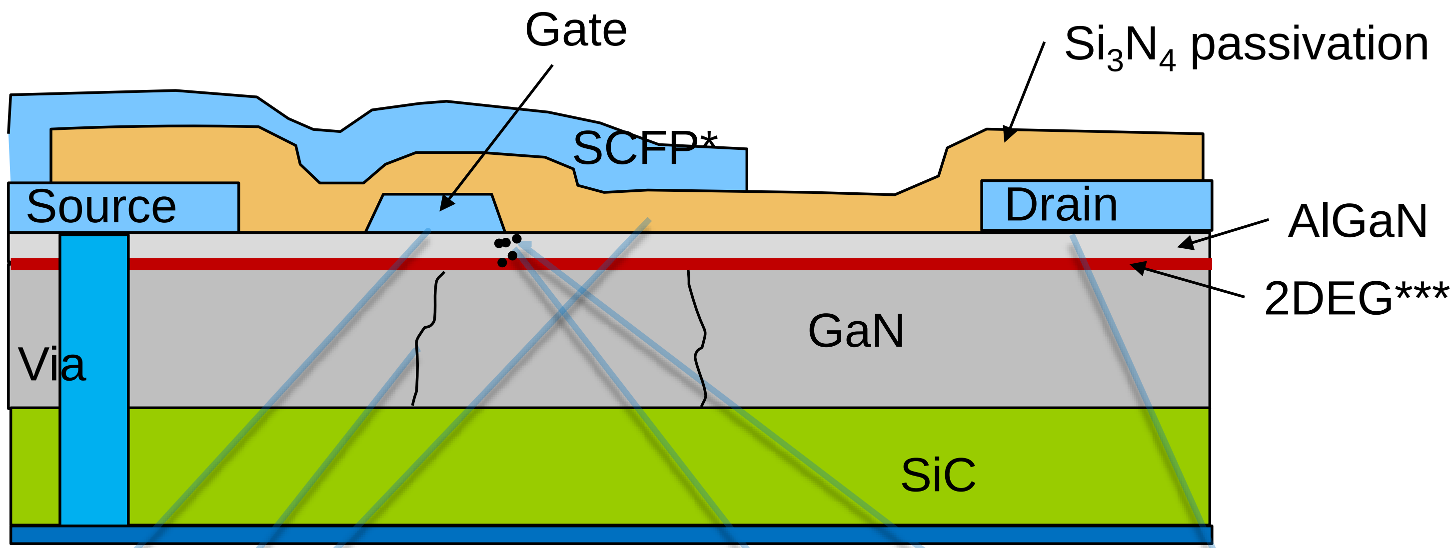
Is GaN "different"?

Well, yes…

- We *cannot* qualify GaN devices in a similar way to previous III-V semiconductors (GaAs, InP)
  - *Multiple failure mechanisms may exist*
  - *(they exist in GaAs too, but the lower voltages/currents/power levels preclude them)*
  - *Gate sinking no longer remains as dominant*
- In our new document we focus on:
  - *microwave/power HEMTs and MMICs*
    - Conventional Schottky gates
    - No enhancement mode devices (very different physics)
    - Typically (but not limited to) SiC substrates
- Qual methods
  - *Intrinsic failure modes*
    - DC multi-temperature lifetests, at multiple bias points
      - *Step-stress / constant stress*
    - RF-driven tests
      - *CW / pulsed*
      - *TLYF (test like you fly)*

Multiple modes demand multiple tests

Some Failure Mechanisms in GaN Power HEMTs



Reliability Concerns:

Gate diffusion, chemical reactions

Source/drain ohmic metal-semiconductor reactions

Pits/cracks – moisture / mechanical stress (IPE**)

Charging/traps- virtual gate (VG)

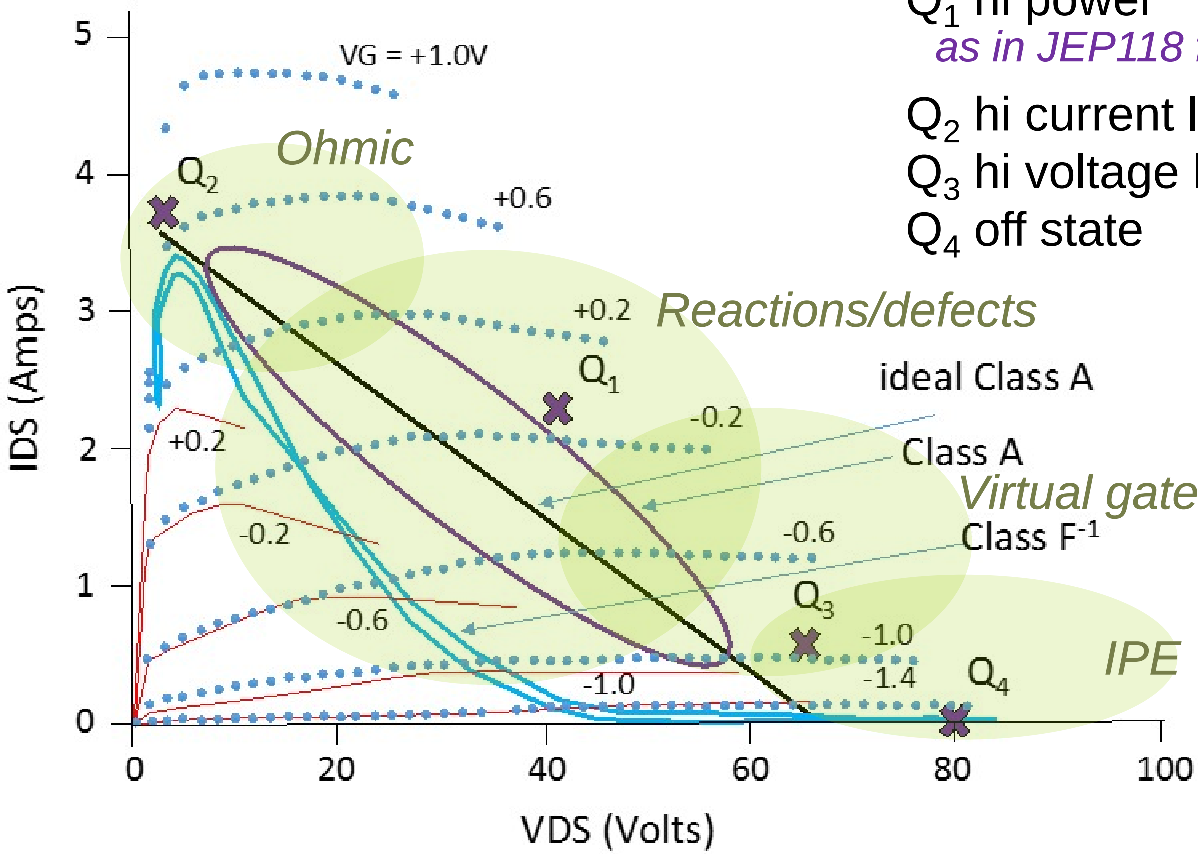
Dislocation defects (throughout)

Point defects (esp. at gate-drain edge)

*Source Connected Field Plate
**Inverse Piezoelectric Effect
***Two Dimensional Electron Gas

Stressing regimes

DC stressing at four operating points (Q-points)



Q_1 hi power
as in JEP118 for GaAs

Q_2 hi current lo voltage

Q_3 hi voltage lo current

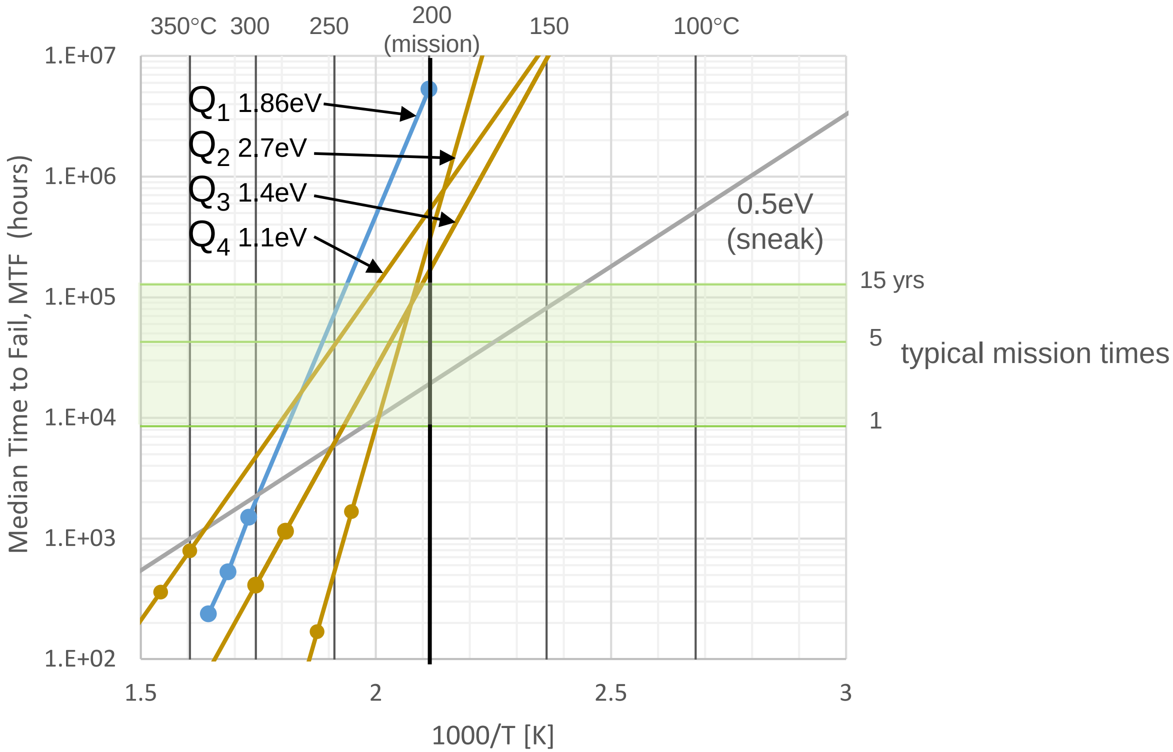
Q_4 off state

- Depending upon the RF load figure different failure modes are manifested
- Devote at least two temperatures to each Q-point

Multiplicity of Intrinsic Failure Modes

With operation over different bias points

- DC lifetest data taken at operating point Q_1
  - *predicts E_A = 1.86eV, MTTF = 5×10^6 hrs at mission temperature 250°C.*
- CAVEATs:
  - *Q_2 - Q_4 give much shorter MTTFs*
  - *A “sneak” low E_A mechanism of 0.5eV could exist - short MTTF*

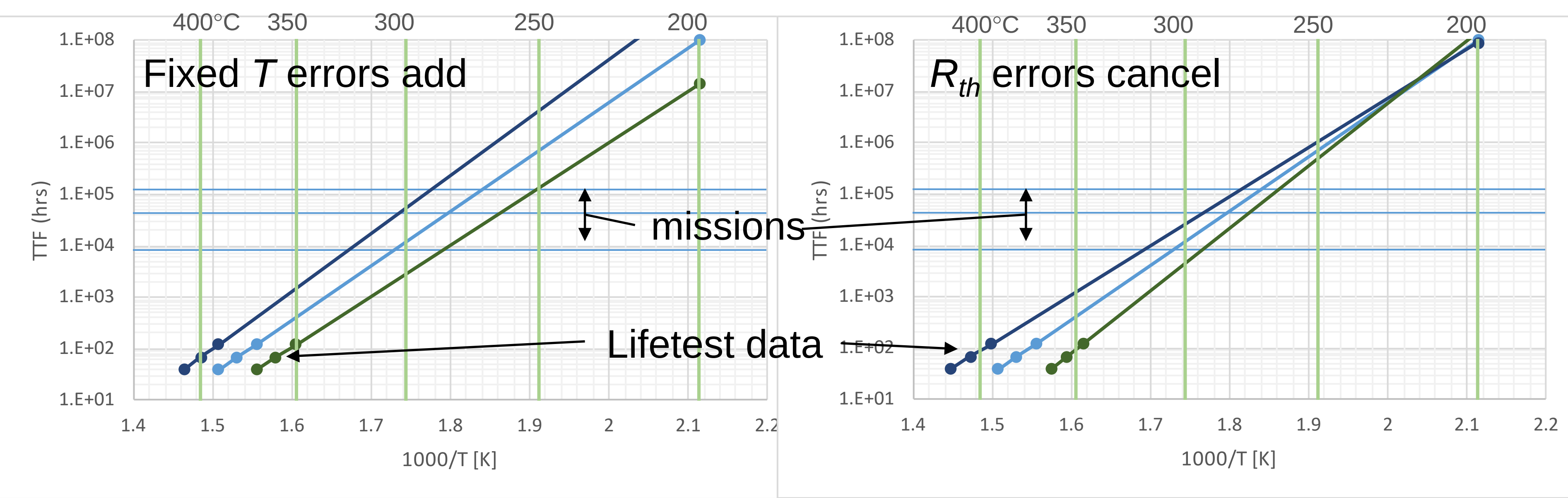


Guidelines are provided for comprehensive test campaigns

Temperature Errors Affect Reliability Predictions

Temperatures are much higher in GaN power HEMTs

- Methods of temperature measurement – guidelines provided
  - *IR thermography*
  - *Raman scattering*
    - Bulk - direct
    - Surface – with nanoparticle sprinkling
  - *Thermoreflectance*
  - *Gate end-end resistance measurement*
  - *Translation from stress power level to usage power level using Rth can introduce additional temperature errors and reliability prediction uncertainties*



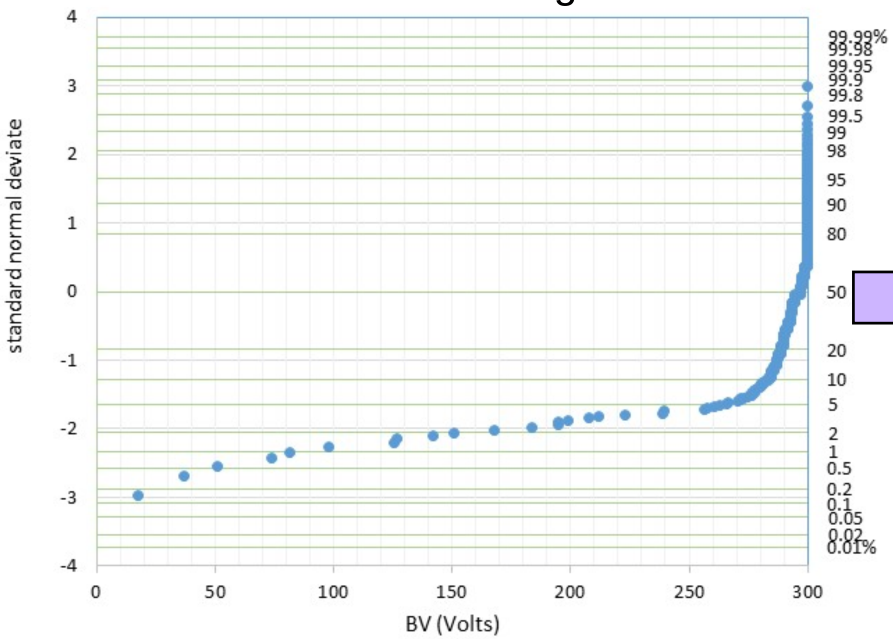
Temperature errors have varied effects- guidelines are provided

Defects

Guidance provided on reliability assessment of process defects

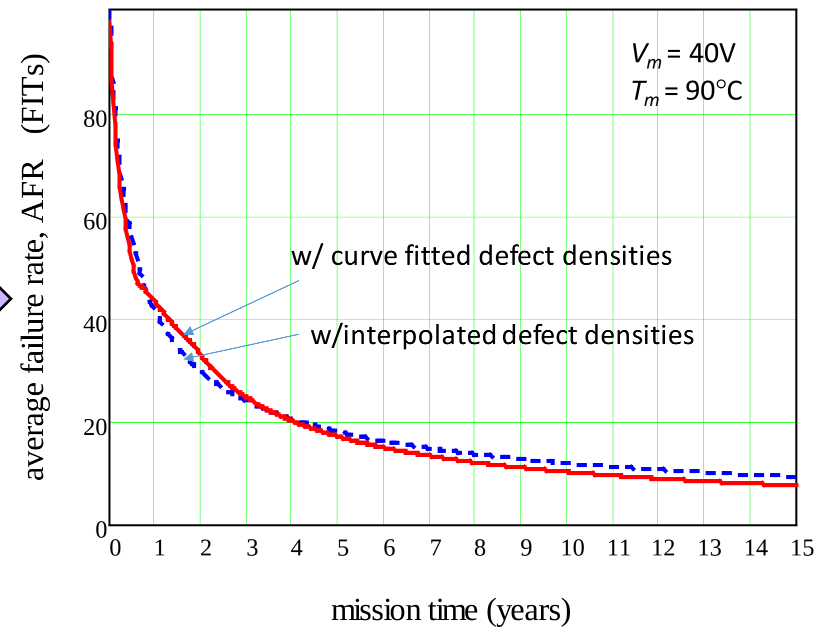
- Example – defects in MIMCAPs
  - *MIMCAPs in GaN technology subjected to much higher voltage than in previous GaAs technology – MIMCAPs may dominate failure rates*

Probplot of ramped breakdown voltages



transformation

FIT rate vs. time



Guidance provided on MIMCAP defect density testing and reliability prediction

More Recommendations & Test Protocols

Topics to consider for space qualification of GaN

- Robustness
  - *SOA (safe operating area)*
  - *Gate burnout*
  - *RF burnout*
  - *ESD*
  - *Temperature cycling*
  - *Power cycling*
  - *Off-state voltage screening*
- Intrinsic Reliability
  - *DC lifetesting (4 Q-points)*
  - *RF lifetesting*
  - *Step stressing*
  - *TLYF (Test Like You Fly)*
  - *Thin film resistors*
  - *Electromigration*
- Environmental Effects
  - *Moisture sensitivity*
  - *Hydrogen sensitivity*
  - *Air Sensitivity*
- Extrinsic Defects
  - *MIMCAPs*
  - *Gate Defects*
  - *Airbridge Defects*
  - *Backside Via defects*
- Mechanical
  - *Backside metal adhesion*
  - *Bondpull tests*
  - *Die shear tests*
  - *Step Coverage*
  - *Low Frequency Oscillations*
- Radiation Effects
  - *Total Ionizing Dose*
  - *Dose Rate*
  - *Singe Event Effects*
  - *Displacement Damage*

Guidelines are provided on these topics and more

Conclusion

- A peer-reviewed and vetted space qualification methodology for GaN power HEMTs and MMICs is now available
- TOR-2018-00691 “Guidelines for Space Qualification of GaN HEMT Technologies” J. Scarpulla, C. Gee
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- THANK YOU!